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76-2-CEMEL

A PHOTO-COMPUTER TECHNIQUE FOR DESIGN AND ANALYSIS OF PERSONAL PROTECTIVE EQUIPMENT

October 1975

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UNITED STATES ARMY
NATICK DEVELOPMENT CENTER
NATICK, MASSACHUSETTS 01760

Clothing, Equipment Materials and Engineering Laboratory

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Combined use of multi-exposure photography and computer analysis provides a reliable technique for measuring a target area presented to or "perceived" by a ballistic fragment array. "Perceived" area is a parameter necessary for casualty reduction analysis of body armor and headgear. The Photo-Computer analysis procedure may be applied to design analysis of the photographs and data matrix. The data matrix can be represented by a series of polynomials or equations. Other applications of the photo-computer techniques include determination of helmet off-set, fit of clothing, comparison of two or

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20. ABSTRACT (Cont'd)

more helmets, component interface and development of contour drawings.

A Photo-Computer Technique For Design and Analysis of Personal Protective Equipment

By
Abraham L. Lastnik
and
Carl W. Gordon

Preface

The contents of this report was presented at, and published in the proceedings of the 13th Conference of the Survival and Flight Equipment Association (SAFE) in San Antonio, Texas on 21 - 26 September 1975.

The Authors thank Dr. Matthew L. Herz, Clothing, Equipment and Materials Engineering Laboratory, NDC, for making the Hewlett Packard computer system available and providing software for measuring and processing surface data.

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List of Illustrations

A Photo-Computer Technique For Design and Analysis of Personal Protective Equipment

INTRODUCTION

Casualty reduction analysis of body armor considers the impact variables which include penetration characteristics of materials, the nature of the hazard(s) being considered, impact angle of impinging fragments or missiles and the target area presented to as perceived by the fragment array.

Areas presented by regular objects can be calculated as perceived from any angle. Areas of irregular objects can be measured by several techniques. Large expanses can be calculated by means of a traverse described by elements such as quadrants, length, degrees, arcs, direction, etc.

Relatively small areas may be measured with a planimeter that considers the criteria involved in a traverse of a large area. Other methods such as counting squares and application of Simpsons Rule[1] for Irregular Areas may be used to estimate small areas.

For a casualty reduction analysis it is necessary to quantify the percent area of the body that is covered by armor as it is "perceived" by a ballistic fragment in an array. Area coverage used in casualty reduction analysis had been determined by diverse ways as devised by each investigator. A search revealed no detailed methods for measuring presented area as related to body armor.

Letters, memorandum reports and personal contacts revealed several methods that generated area numbers that had been used for casualty reduction analysis. Two of these methods are outlined to illustrate the diversity of techniques used:

a. An armored vest was fitted on an anthropometric dummy, the areas covered by the vest were outlined on the dummy's surface. The defined areas were traced onto a thin plastic film that was somehow applied to the dummy. The traced segment was cut out of the sheet and the area was determined by a weighing technique.[2]

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[1] Simpsons Rule for Irregular Areas:
Divide area into n panels (where n is an even number) by means of parallel lines, or ordinates drawn at constant distance h apart; designate the length or ordinates by $y_0, y_1, y_2, \ldots y_n$. The first and last ordinate may be zero. Then area will be:
$A = 1/3\ h\ [(y_0 + y_n) + 4(y_1 + y_3 + y_5) + 2(y_2 + y_4 + y_6 \ldots)]$

[2] Letter Report AMXRD-BVL (Woodward), 10 Aug 70, SUBJECT: Body Area Coverage Afforded by U.S. Army 12-Ply Nylon and US Marine Corps Doron Plate Armored Vests.

b. Biostereometric photographic methods have been proposed as a means for estimating the cumulative covered fraction of all views of the body that is covered by the vest.[3]

This report presents a reliable technique for determining presented area and percent of the body that would be covered by armor when viewed from a multiplicity of angles in any plane. Through use of photographic and computer analysis techniques, reliable area coverage data may be developed.

Apparatus Used

a. Sierra Engineering Company 50th percentile anthropometric dummy.

b. Head model, medium size, developed by Natick Development Center.[4]

c. Polaroid MP-4 photographic system.

d. Hewlett Packard 9810A Calculator.

e. Hewlett Packard 9864A Digitizer.

f. Computer terminal tied into Computer Sciences Corp. Infonet time sharing service.

Method

Armored Vest

An anthropometric dummy was suspended (Fig. 1) by an eyebolt centered on the head, so that the dummy stood erect with its feet resting on a pedestal. A perpendicular dropped from the eyebolt denoted a center on the pedestal around which 15-degree increments were generated through 360-degrees. The dummy could then be rotated through 360-degrees at selected increments.

For a specific study, the dummy was photographed at 15-degree intervals from 0 through 180-degrees.

At each increment, a double exposure picture was made; the dummy was photographed first with an armored vest, and then without the vest on the same plate. The result was an x-ray like photograph showing the body and all of its benchmarks through the armor. (Fig. 2)

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3 Herron, R.E., "Biostereometric Measurement of Body From" Yearbook of Physical Anthropology, 1972, Vol. 16, pp 80 - 120.

4 Claus, W.D. Jr., McManus, L.R. and Durand, P.E., "Development of Headforms for Sizing Infantry Helmets", Technical Report 75-23-CEMEL, US Army Natick Laboratories (Mass), June 1974.

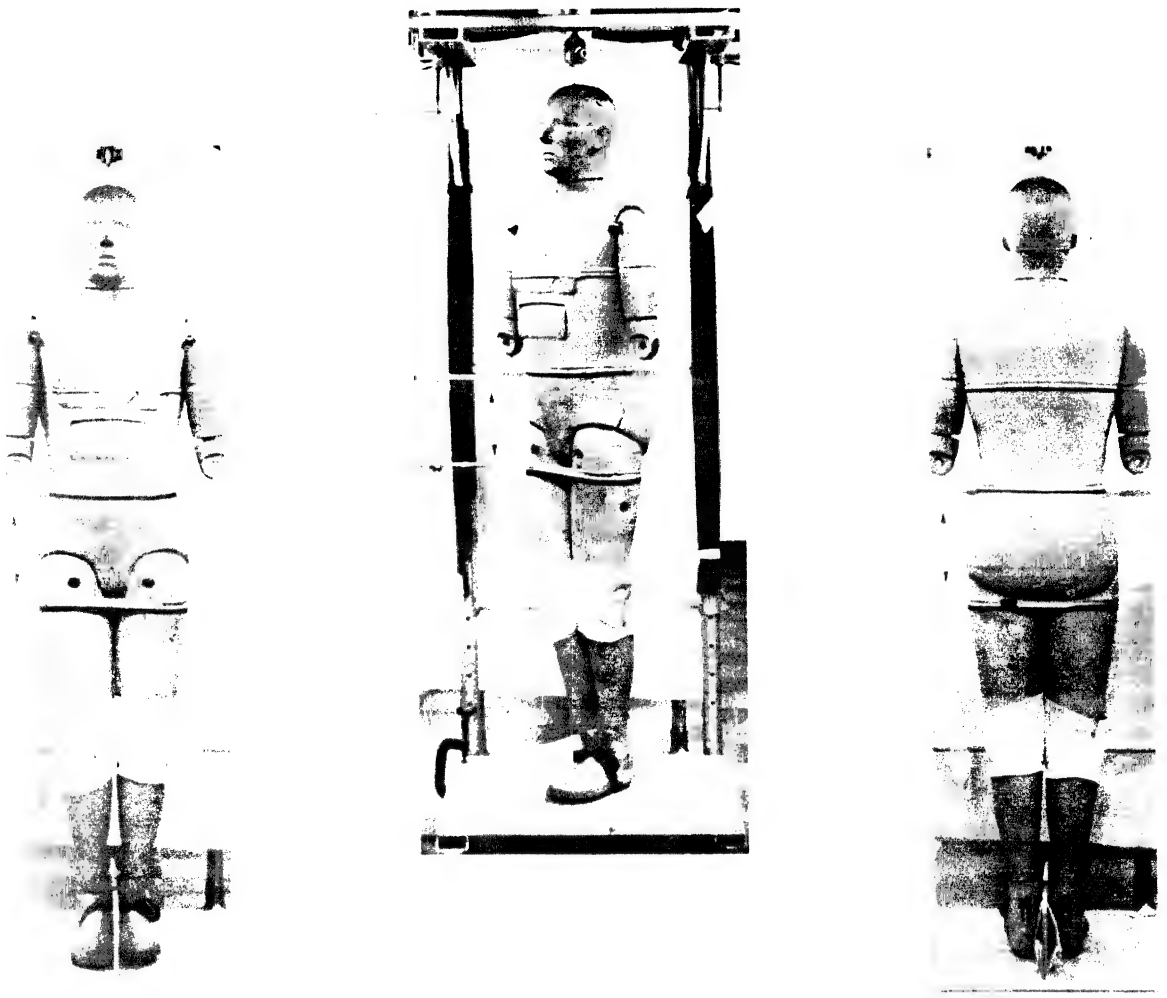
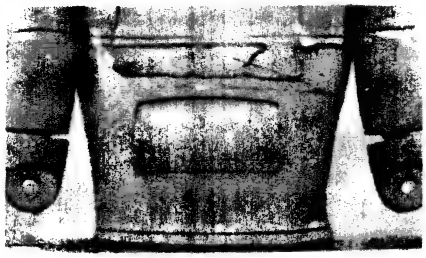


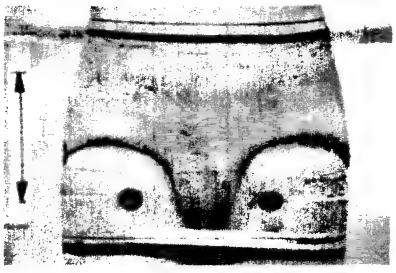
FIG. 1 50TH PERCENTILE ANTHROPOMETRIC DUMMY SUSPENDED AND PREPARED FOR INCREMENTAL ROTATION PHOTOGRAPHING.

For the armored vest studies the torso was divided into three zones: thorax, abdomen and pelvis (Fig. 3).[5,6] Each zone in the original photograph was enlarged to the same degree of magnification. The area of the body perceived at each increment in each zone was measured on the photograph(s) with a digitizer.

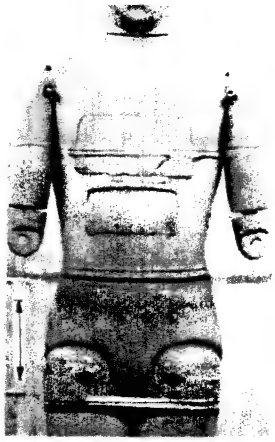
THORAX



ABDOMEN



PELVIS



TORSO

FIG. 3 ANTHROPOMETRIC DUMMY SEGMENTED INTO SPECIFIED AREAS OF A DEFINED TORSO.

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5 Memorandum for Record, STSNL-VCA, 21 Oct 74, SUBJECT: Report of Travel of Mr. T. Keville to Aberdeen Proving Ground, on 16 - 17 Oct 74 Re: Armor Coverage.

6 Memorandum for Record, AMXRE-CCE, 5 June 73, SUBJECT: Report of Travel of Ms. Louise V. Dusablon to Ballistic Research Laboratories, Aberdeen Proving Ground, Maryland, 10 - 11 May 72.

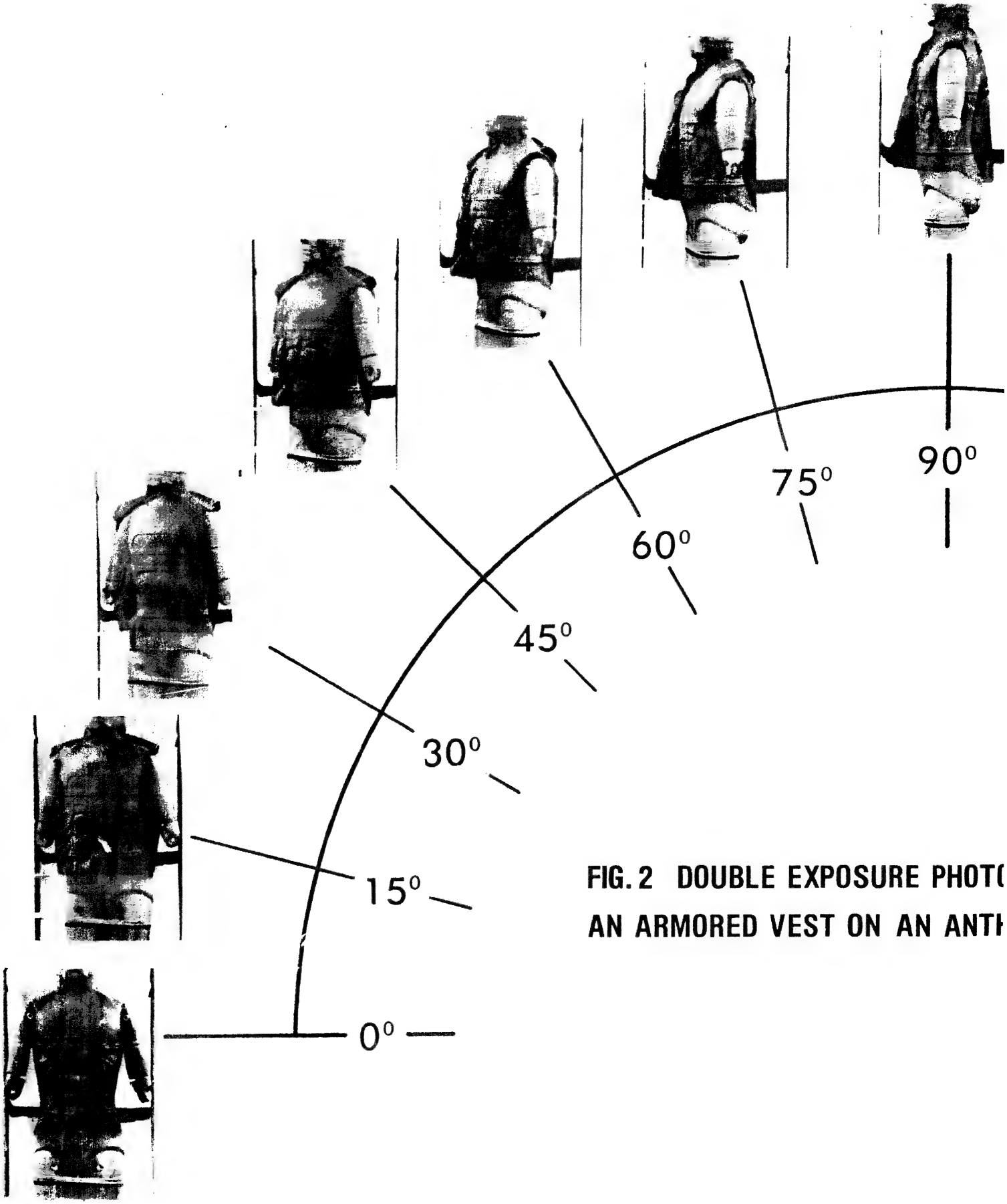
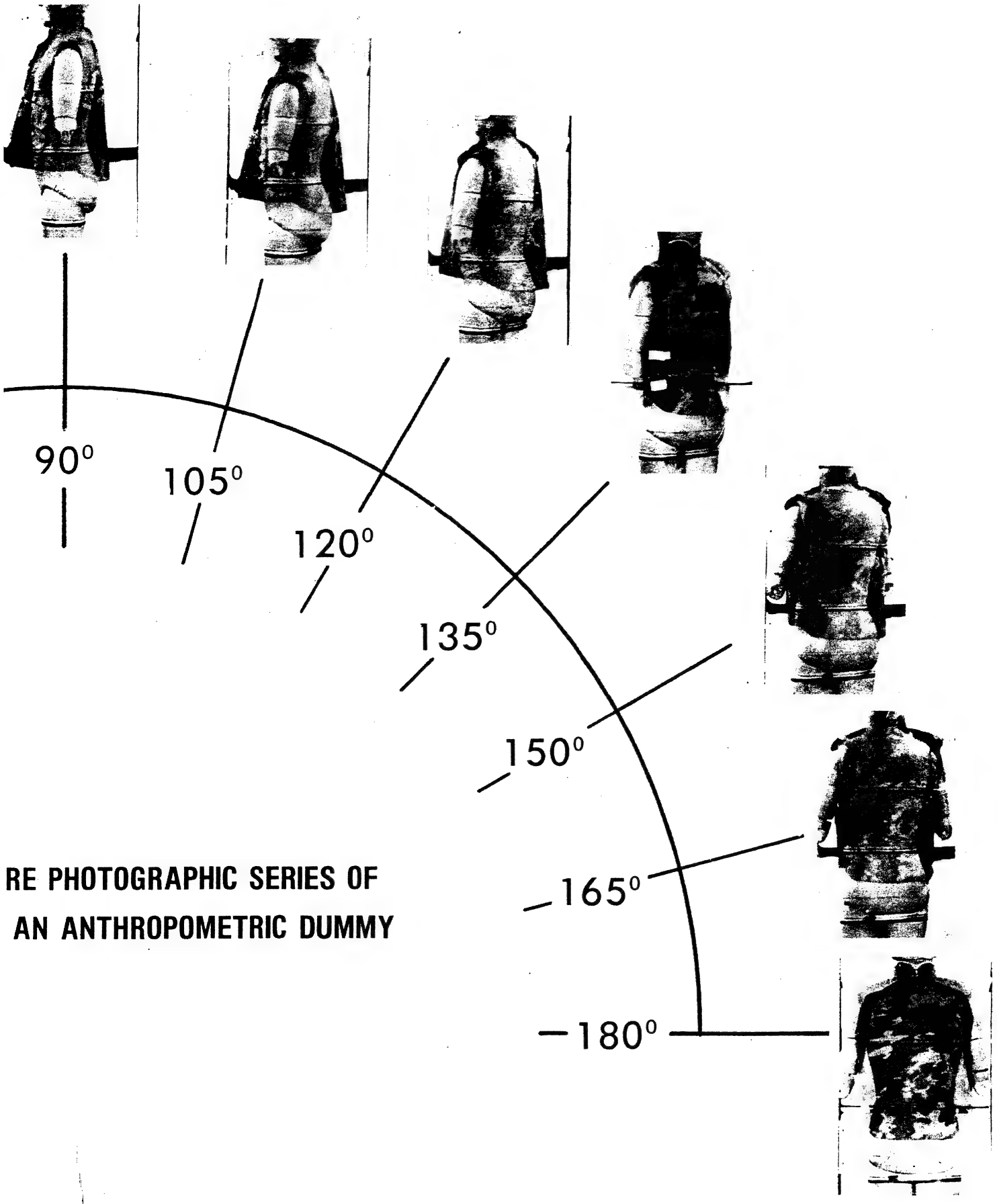


FIG. 2 DOUBLE EXPOSURE PHOT(
AN ARMORED VEST ON AN ANTI



RE PHOTOGRAPHIC SERIES OF AN ANTHROPOMETRIC DUMMY

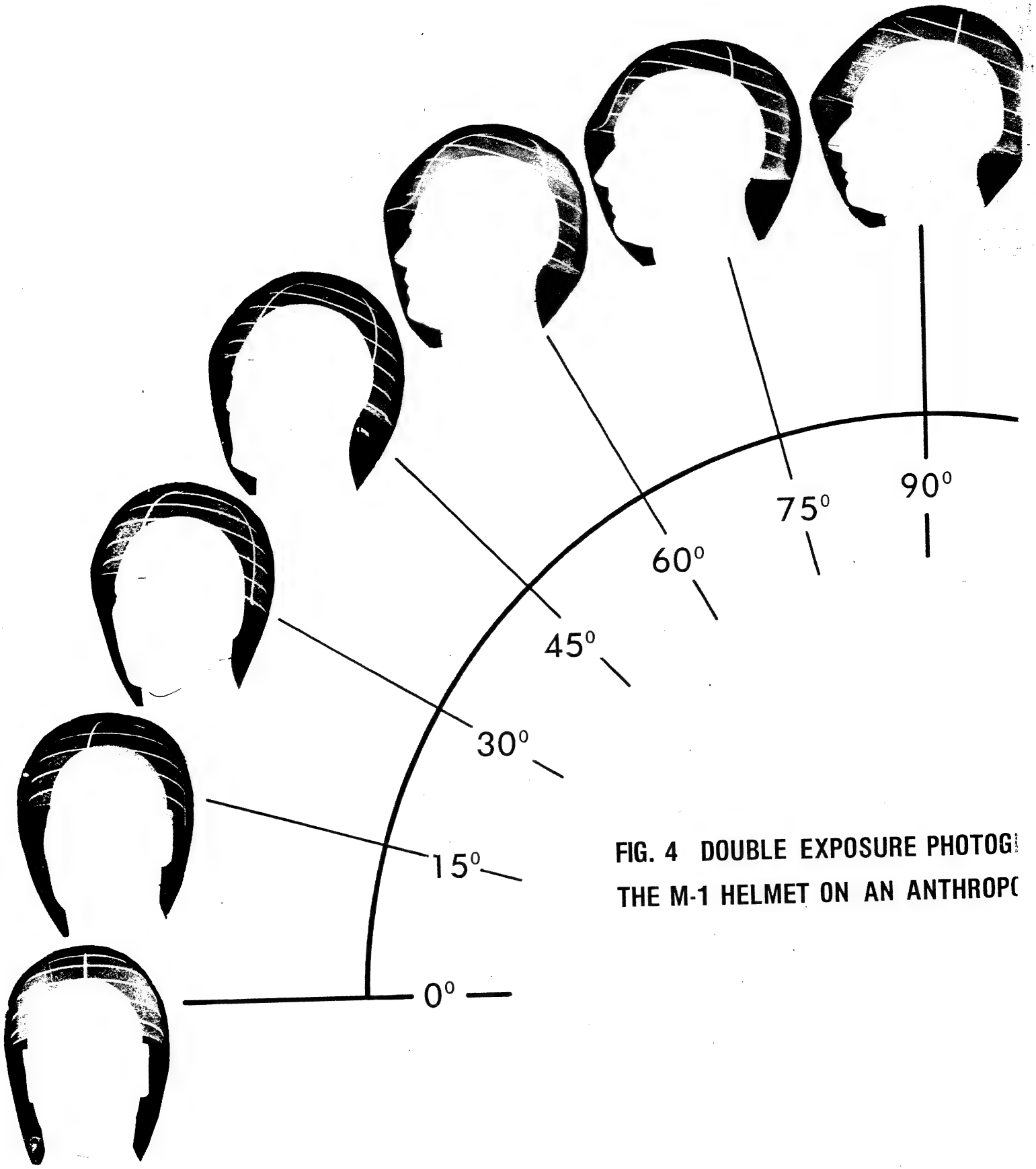
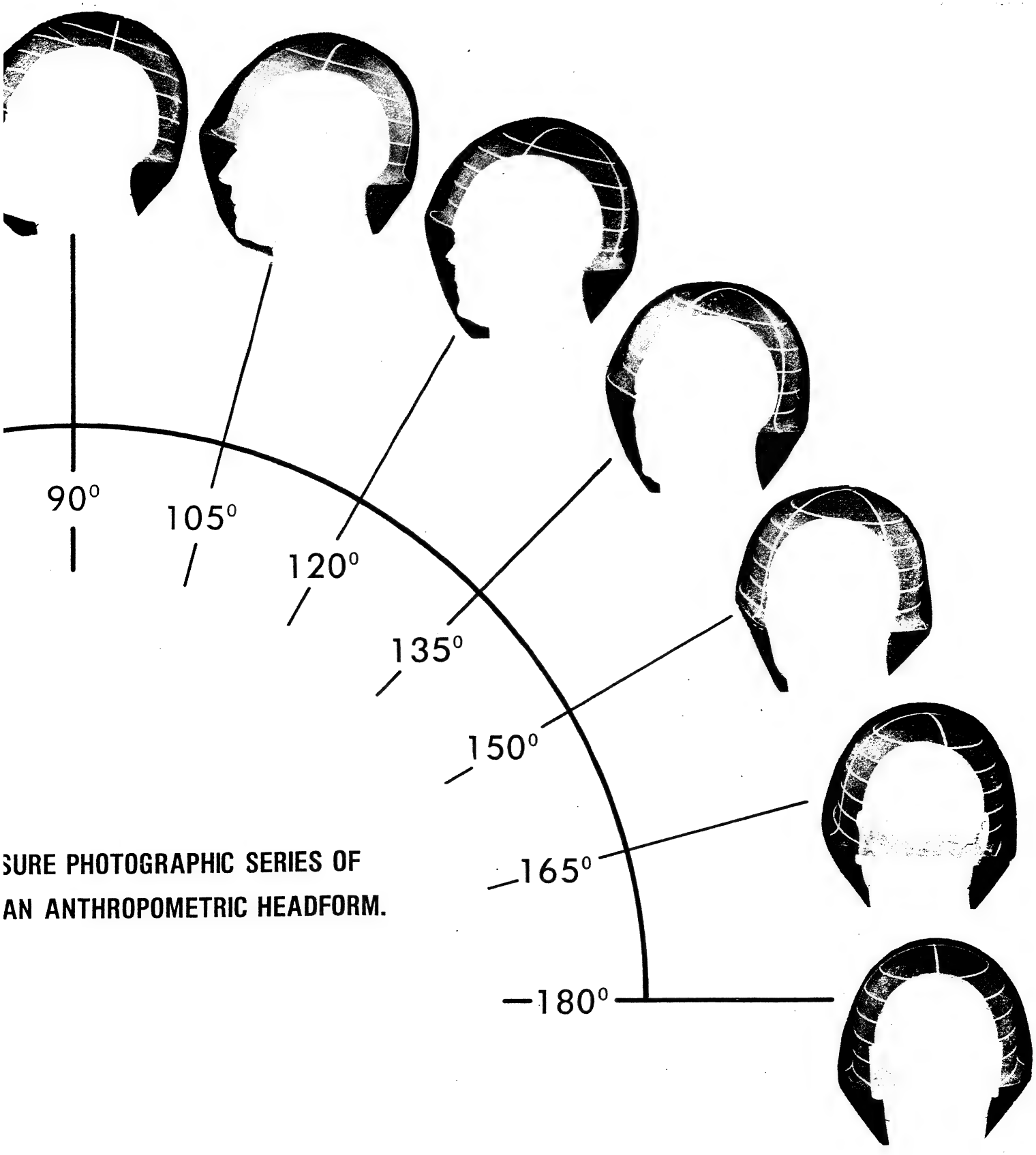


FIG. 4 DOUBLE EXPOSURE PHOTOG
THE M-1 HELMET ON AN ANTHROPC



SURE PHOTOGRAPHIC SERIES OF
AN ANTHROPOMETRIC HEADFORM.

Helmets

A medium size head model[7] was fixed on a dividing head so that a full face view was presented at 0-degrees.

For a specific study, the headform was photographed at intervals of 15-degrees from 0-degrees through 180-degrees. At each increment a double exposure picture was made; the first exposure was made with a helmet on the headform and the second, with the headform alone on the same plate. The result was an x-ray like photograph showing the head through the helmet. Each photograph was enlarged to the same degree of magnification. The area of the head perceived at each (Fig. 4) increment was measured on the photograph(s) with a digitizer. The data generated by the digitizer were converted to square feet and percentage of area covered by the helmet. These data were then recorded as data files in a computer memory for future use (Fig. 5). This type of area data and recording in computer memory was also done for body armor. Similar studies can be made by varying the elevation of the helmet in any selected view. Figure 6 depicts the helmet viewed at 0-degrees and moved through a vertical arc from minus 45 thru 90-degrees in 15-degree increments.

Photo-Methodology

Since the photographic data serves as a base for all subsequent data to be developed, it is most important that it be accurate and reproducible. To accomplish this special problems, as well as those inherent in still life photography, were to be resolved in order to develop a reliable data base.

Parallax

The greatest source of measurement error was due to the distortion of the photographed area because of parallax. The error introduced by parallax can be eliminated by photographing the subject from an indefinite distance; thus, parallax is generally minimized by photographing the subject from great distances using telephoto lenses. The selected details are subsequently enlarged to a reasonable working size.

For the studies made at Natick Development Center the error introduced by parallax was minimized so that it would be within the 1% error inherent in the measuring technique. A 135mm f/4.5 flat focus lens was used to focus on the vertical axis of the anthropometric dummy from distance of 480.7 $\pm$ 0.6cm ($189\frac{1}{4} \pm \frac{1}{4}$in.). For the head, the focusing distance was 137 $\pm$ 0.6cm ($54 \pm \frac{1}{4}$in.). Proper alignment of the subject(s) in the horizontal and vertical planes with respect to the lens axis is critical for minimizing image distortion. (Fig. 7)

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[7] See footnote 4 on page 6.

COLUMNS	1	2	3	4
DATA MATRIX				
ROW 1	338	211	105	000
ROW 2	349	223	115	15 000
ROW 3	357	255	131	30.000
ROW 4	378	282	161	45 000
ROW 5	393	316	191	60 000
ROW 6	397	340	210	75.000
ROW 7	394	375	232	90 000
ROW 8	383	392	250	105.000
ROW 9	355	404	258	120 000
ROW 10	331	386	226	135.000
ROW 11	245	359	190	150.000
ROW 12	237	331	184	165 000
ROW 13	235	326	176	180.000
ROW 14	237	331	184	195.000
ROW 15	245	359	190	210 000
ROW 16	331	386	226	225 000
ROW 17	355	404	258	240 000
ROW 18	383	392	250	255 000
ROW 19	394	375	.232	270.000
ROW 20	397	340	210	285.000
ROW 21	393	.316	.191	300.000
ROW 22	378	282	161	315.000
ROW 23	357	255	.131	330.000
ROW 24	349	223	115	345.000

FIG. 5 DATA MATRIX DEVELOPED BY DIGITIZING M1 HELMET ON AN ANTHROPMETRIC HEADFORM.

COLUMNS:

1. **AREA OF HEAD IN SQUARE FEET**
2. **AREA OF HELMET IN SQUARE FEET**
3. **AREA OF HEAD COVERED BY HELMET IN SQUARE FEET**
4. **PERCEIVED ANGLE IN DEGREES**

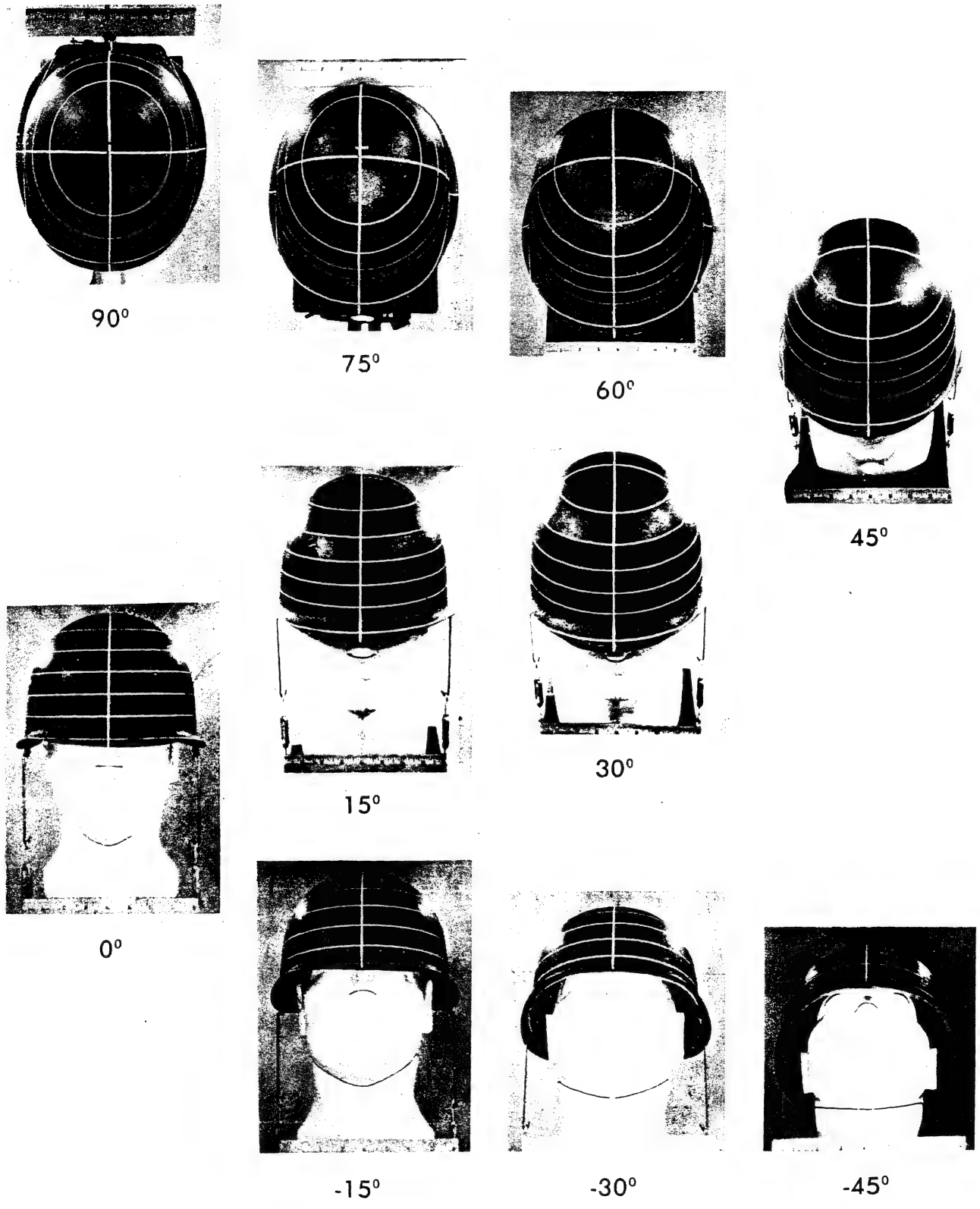

FIG. 6 HELMET VIEWED AT 0-DEGREES AND ROTATED THROUGH A VERTICAL ARC OF 135 DEGREES IN 15 DEGREE INCREMENTS

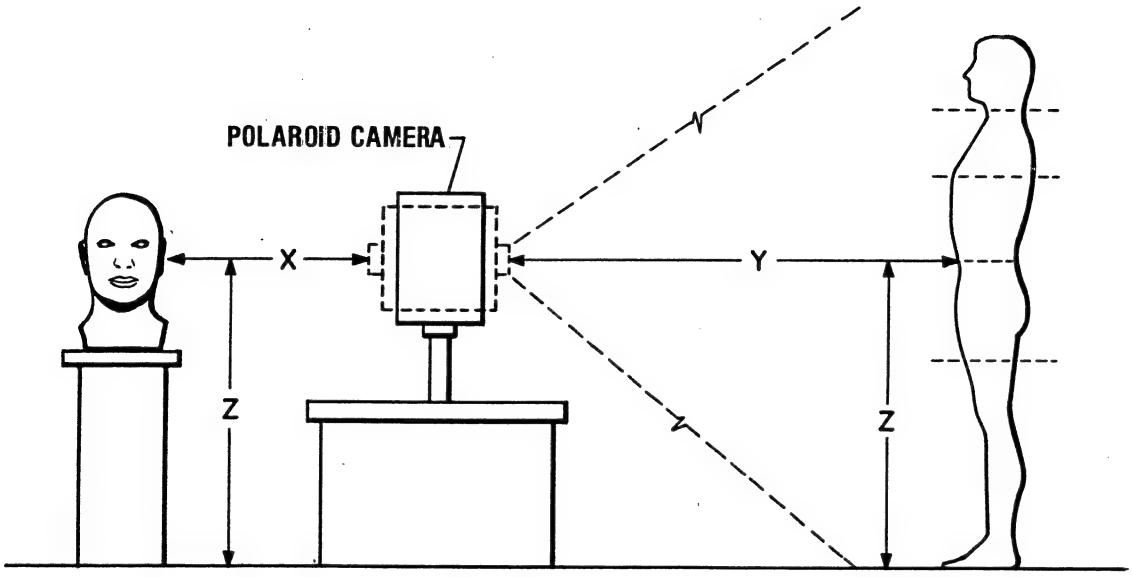

FIG. 7 SCHEMATIC OF PHOTOGRAPHIC CENTER SHOWING CRITICAL DISTANCES.

Multiple Image Photography

Double and triple exposure photographing was used to achieve x-ray like pictures showing the head or body through armor. For these multiple exposures, the accepted method of under-exposing; i.e., each exposure for a double exposure taken at one F-stop below the normal stop, can be used. In order to highlight or to de-emphasize selected details, variations in color and/or lighting effects must be considered. Exposures necessary to compensate for these variations are somewhat different from those that one skilled in the art would normally expect to use. Further, these variations occurred erratically so that a rule could not be developed for general guidance. Each condition was evaluated and the lighting and exposure conditions were formulated to emphasize or diminish desired details. For the studies to support casualty reduction analysis, the normal overhead fluorescent lights were used. An additional ring of light around the camera lens was used when the head was photographed. Background colors of white, black, yellow, orange, red and gray were used to achieve appropriate contrasts between exposures.

Enlarging

Each photograph was enlarged so that the desired detail made a 4 x 5 print (Fig. 3). Care was taken to assure that the enlargements of any one series were in the same scale of magnification. Further, a reference dimension was included on each photograph. On the anthropometric dummy, marked distances from the base (floor) defines the pelvis, abdomen and throax. In each picture of the anthropometric dummy there was also depicted a six inch reference line. The width and length of the headform served as the reference dimensions. (Fig. 8) On all multiple exposure helmet/headform photographs the vertical distance from the tip of the nose to the brim of the helmet was fixed to maintain proper alignment and positioning of the helmet; it also served as a reference line for scaling of the photograph.

A 35mm f/35 lens was used. All other common procedures for enlarging were followed. Special effort was made to maintain the photograph flat and parallel to the film plane. The photograph was centered precisely with the axis of the lens.

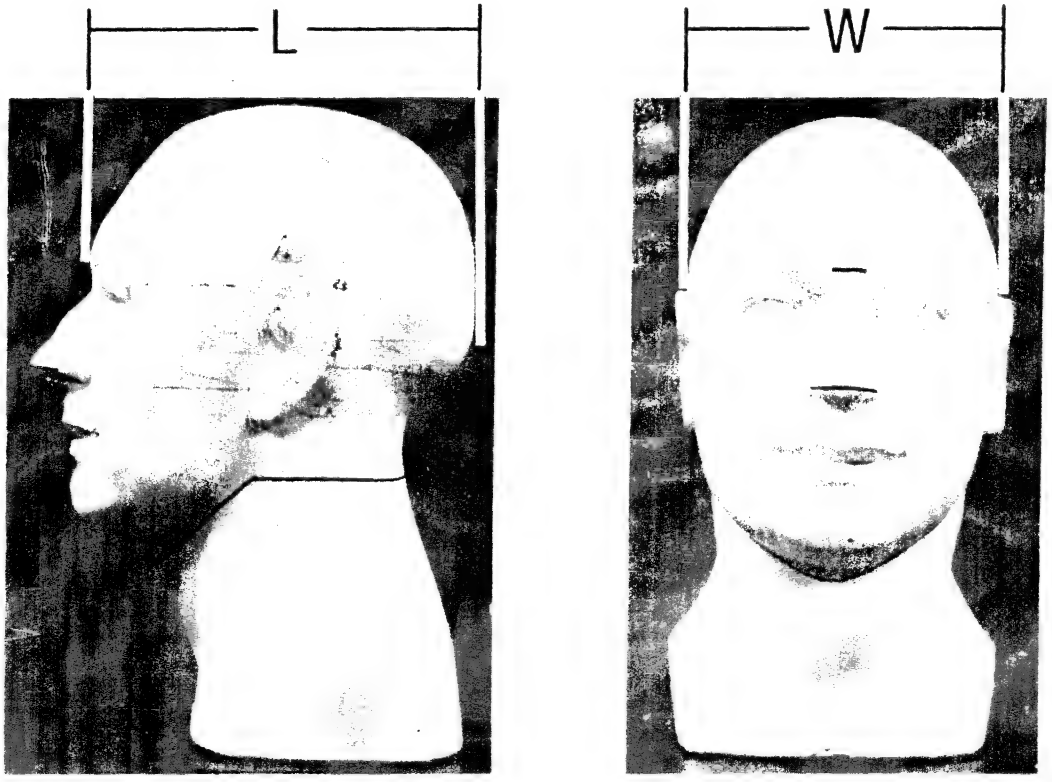

FIG. 8 ANTHROPOMETRIC HEADFORM SHOWING CONSTANT DIMENSIONS USED FOR SCALING PHOTOGRAPHS.

Applications

a. Casualty Reduction Studies

Average perceived area coverage of the torso and head were determined by processing the data through a statistical program[7] that provided the average area, standard deviation and standard error (Fig. 9).

VARIABLE	MEAN	STD.DEV.	STD.ERR.	MAXIMUM	MINIMUM	RANGE
1	.342	.058	.012	.397	.235	.162
2	.328	.060	.012	.404	.211	.193
3	.191	.047	.010	.258	.105	.153
4	172.500	106.066	21.651	345.000	.000	345.000

VARIABLE	
1	AREA OF THE HEAD IN SQ.FT.
2	AREA OF THE HELMET IN SQ.FT.
3.	AREA OF THE HEAD COVERED BY THE HELMET IN SQ.FT.
4	PERCEIVED ANGLE IN DEGREES

FIG. 9 ELEMENTARY STATISTICAL ANALYSIS OF AREA OF THE HEADFORM COVERED BY THE M1 HELMET. VARIABLE 4 REPRESENTS THE PERCEIVED ANGLE AND CANNOT BE CONSIDERED IN THIS ANALYSIS.

b. Perceived Area from Angle in a Plane

Collected data of body armor and helmet were processed through a statistical program[8] that computed a least-squares polynomial curve fit between an independent and dependent variable. The angle 0 - 345 (in 15 increments) was the independent variable and the "perceived" area of the torso or helmet then processed through a program to solve an n^{th} degree polynomial for the covered area of the head perceived at any desired angle (Fig. 10).

---

[7] Computer Sciences Corporation, Information Network Division of, INFONET CSCX Basic Library "Elementary Statistics" ***STATPK Subprogram, Miscellaneous Routines 06.01, Program No. 03-1811.

[8] Computer Sciences Corporation, Information Network Division of, INFONET CSCX Basic Library "Polynomial Regression" ***STATPK Subprogram, Miscellaneous Routines 06.01, Program No. 03-1823.

POLYNOMIAL REGRESSION OF DEGREE 6

INTERCEPT..... 1.10150E-01

REGRESSION COEFFICIENTS

1	-2.36278E-03
2	1.50366E-04
3	-2.00830E-06
4	1.12518E-08
5	-2.84205E-11
6	2.66233E-14

STANDARD ERROR OF ESTIMATE .01516
CORRELATION COEFFICIENT... .960720
R-SQUARED..... .922983

FIG. 10 INTERCEPT AND REGRESSION COEFFICIENTS OF A 6TH DEGREE POLYNOMIAL THAT REPRESENTS THE PERCEIVED AREA OF A HEADFORM COVERED BY THE M1 HELMET.

c. Comparisons

Collected data of up to three body armors or helmets were processed through a statistical program[9] which computes and prints a line plot for one independent and up to three dependent variables. Figure 11 shows a plot comparing the area of three helmets when viewed in 15-degree increments. These plots also depict the contour of the peripheral edge in sufficient detail to show that one helmet has a small undercut juxtaposition with the canthus of the eye (at 60 and 75-degrees, experimental helmet 1 covers less of the head than experimental helmet 2). Figure 12 is a triple exposure photograph which compares the contours and fit of two helmets on a headform.

d. Computer Assisted Design

Visual comparisons can be made and related to the perceived area covered by the armor. Modifications can then be made to increase or decrease the area covered. Figure 12 compares the standard helmet and experimental helmet. The bottom curved white line on the triple exposure photograph in Fig. 12 defines the peripheral edge of the standard helmet.

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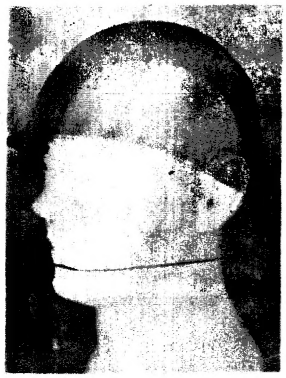
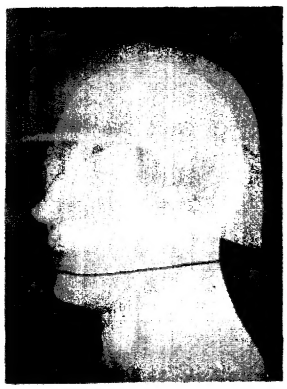
9 Computer Sciences Corporation, Information Network Division of, INFONET CSCX Basic Library "Line Plot" ***STATPK Subprogram, Miscellaneous Routines 06.01, Program No. 03-1816.



LINER



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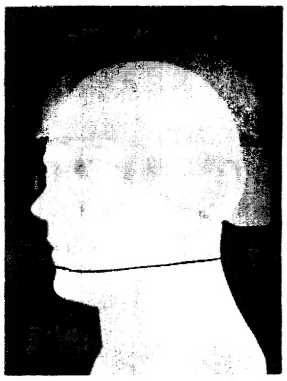

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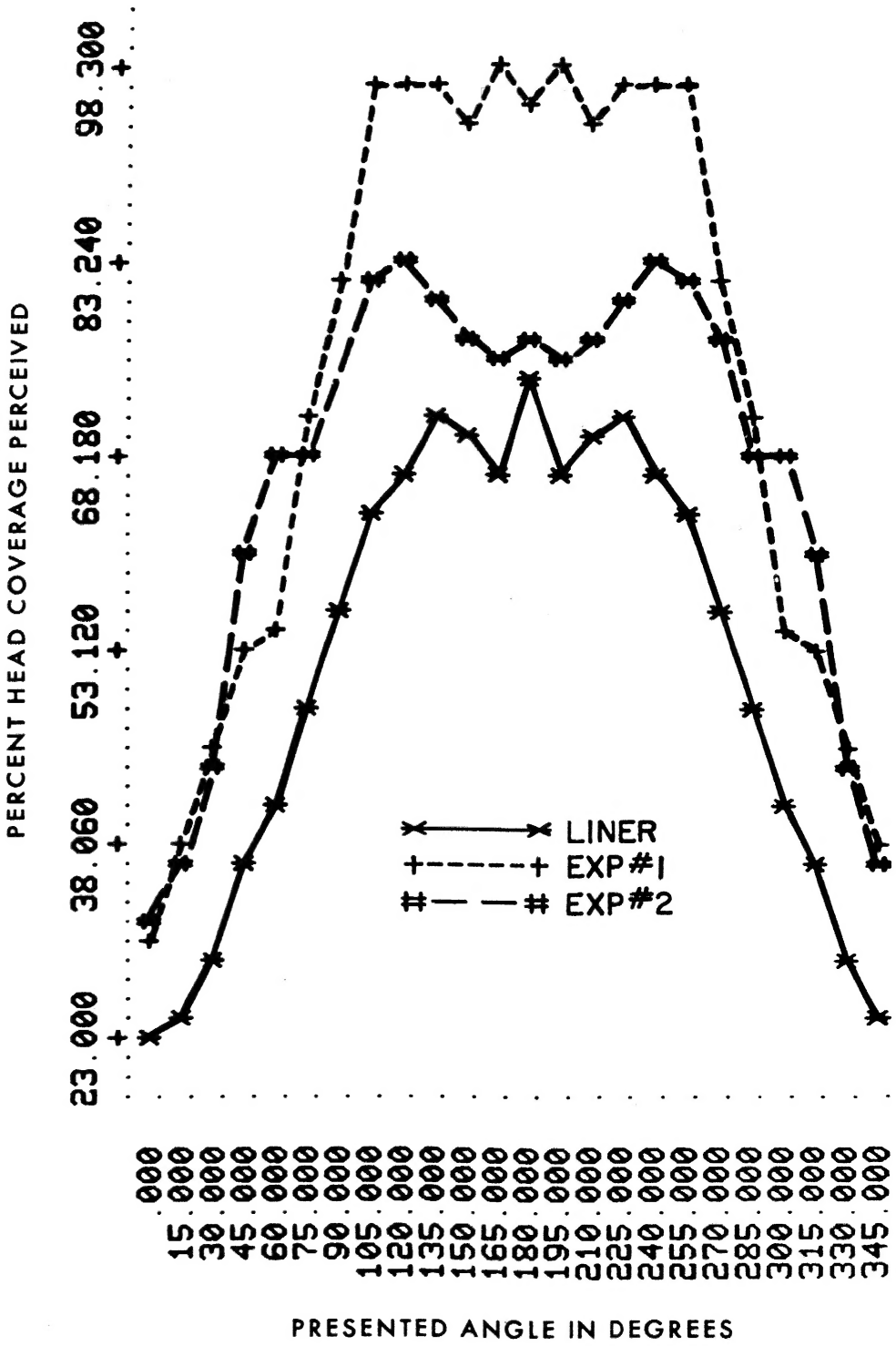

FIG. 11 COMPARISON OF AREA OF MEDIUM SIZE HEAD THAT WILL BE COVERED HELMETS WHEN PERCEIVED FROM A VARIETY OF ANGLES IN A HORIZONTAL PL

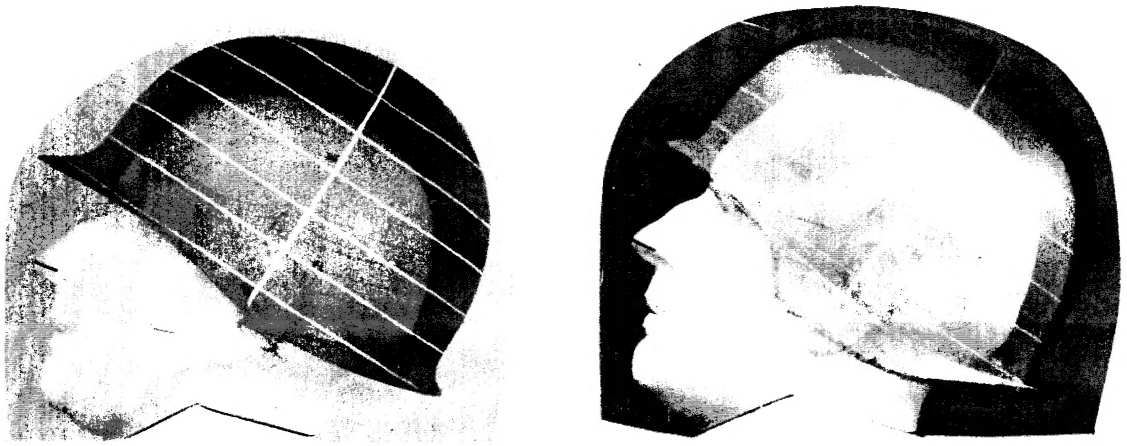

FIG. 12 DOUBLE AND TRIPLE EXPOSURES SHOWING HELMET (S) ON HEADFORM. COLOR SHADES: LIGHTEST=HEADFORM, DARKEST=M1 HELMET, INTERMEDIATE= EXPERIMENTAL HELMET.

Component fit or interface can easily be determined, using multiple exposure photography. The off-set of various size helmets from the head, is readily apparent. Design modifications can be made based on evaluation of these photographs.

Contour drawings can be developed in either the polar or cartesian coordinate systems from the photographs.